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COMPARATIVE STUDIES UPON THE GLACIATION OF NORTH AMERICA, GREAT BRITAIN AND IRELAND.[1]

BY PROFESSOR H. CARVILL LEWIS.

OBSERVATIONS extending over several years upon glacial phenomena on both sides of the Atlantic had convinced the author of the essential identity of these phenomena; and the object of this paper was to show that the glacial deposits of Great Britain and Ireland, like those of America, may be interpreted most satisfactorily by considering them with reference to a series of great *terminal moraines*, which both define confluent lobes of ice, and often mark the line separating the glaciated from the non-glaciated areas.

The paper began with a sketch of recent investigations upon the glaciation of North America, with special reference to the significance of the terminal moraines discovered within the last few years. The principal characters of these moraines were given, and a map was exhibited showing the extent of the glaciated areas of North America, the course of the interlobate and terminal moraines, and the direction of striation and glacial movement. It was shown that apart from the great ice-sheet of Northeastern America, an immense lobe of ice descended from Alaska to Vancouver's island on the western side of the Rocky mountains, and that from various separate centers in the Cascade, Sierra Nevada and Rocky mountains there radiated smaller local glaciers.

The mountains encircling the depression of Hudson bay seemed to be the principal source of the glaciers which became confluent to form the great ice-sheet. In its advance this ice-sheet probably met and amalgamated with a number of already existing local glacial systems, and it was suggested that there was no necessity for assuming either an extraordinary thickness of ice at the pole or great and unequal elevations and depressions of land.

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[1] Abstract of a paper read at the Birmingham meeting of the British Association, September, 1886.

Detailed studies made by the author in Ireland, in 1885, had shown remarkably similar glacial phenomena.

The large ice-sheet which covered the greater part of Ireland was composed of confluent glaciers, while distinct and local glacial systems occurred in the non-glaciated area. The principal ice-sheet resembled that of America in having for its center a great inland depression surrounded by a rim of mountains.

These appear to have given rise to the first glaciers, which after uniting poured outwards in all directions. Great lobes from this ice-sheet flowed westward out of the Shannon and out of Galway, Clew, Sligo and Donegal bays, northward out of Loughs Swilly and Foyle, and south-eastward out of Dundalk and Dublin bays, while to the south the ice-sheet abutted against the Mullaghareirk, Galty and Wicklow mountains or died out in the plains.

Whether it stopped among the mountains or in the lowlands its edge was approximately outlined by unusual accumulations of drift and boulders, representing the terminal moraines. As in America, this outer moraine was least distinct in the lowlands, and was often bordered by an outer fringe of drift several miles in width.

South of an east and west line extending from Tralee to Wexword is a non-glaciated zone free from drift. Several local systems of glaciers occur in the south of Ireland, of which by far the most important is that radiating from the Killarney mountains, covering an area of 2000 square miles, and entitled to be called a local ice-sheet. Great glaciers from this Killarney ice-sheet flowed out of the fiord-like parallel bays which indent the south-western coast of Ireland. At the same time the Dingle mountains, the Knockmeal down and Comeragh mountains, and those of Wexford and Wicklow, furnished small separate glaciers, each sharply defined by its own moraine.

No evidence of any great marine submergence was discovered, although the author had explored the greater part of Ireland, and the eskers were held to be phenomena due to the melting of the ice and the circulation of subglacial waters. The Irish ice-sheet seemed to have been joined at its north-eastern corner by ice coming from Scotland across the North channel. All the evidence collected indicates that a mass of Scotch ice, reinforced by that of Ireland and England, filled the Irish sea, overriding the Isle of Man and Anglesey, and extending at least as far south as Bray Head, south of Dublin. A map of the glaciation of Ireland was exhibited in which the observations of the Irish geologists and of the author were combined, in which was shown the central sheet, the five local glacial systems, all the known striæ, and the probable lines of movement as indicated by moraines, striæ and the transport of erratics.

The glaciation of Wales was then considered. Wales was shown to have supported three distinct and disconnected local systems of glaciers, while at the same time its extreme northern border was touched by the great ice-lobe of the Irish sea. The most extensive local glaciers were those radiating from the Snowden and Arenig region, while another set of glaciers radiated from the Plinlimmon district and the mountains of Cardiganshire, and a third system originated among the Brenockshire beacons. The glaciers from each of these centers transported purely local boulders and formed well-defined terminal moraines. The northern ice-lobe, bearing granite boulders from Scotland and shells and flints from the bed of the Irish sea, invaded the northern coast but did not mingle with the Welsh glaciers. It smothered Anglesey and part of Carnarvonshire on the one side, and part of Flintshire on the other, and heaped up a terminal moraine on the outer flanks of the North Welsh mountains. This great moraine, filled with far-traveled northern erratics, is heaped up in hummocks and irregular ridges, and is in many places as characteristically developed as anywhere in America. It has none of the characters of a sea-beach, although often containing broken shells brought from the Irish sea. It may be followed from the extreme end of the Lleyn peninsula (where it is full of Scotch granite erratics) in a north-easterly direction through Carnarvonshire past Moel Tryfan and along the foot of the mountains east of Menai strait to Bangor, where it goes out to sea, reappearing further east at Conway and Colwyn. It turns south-eastward at Denbigshire, going past St. Asaph and Halkin mountain. In Flintshire it turns southward and is magnificently developed on the eastern side of the mountains, at an elevation of over 1000 feet between Minera and Llangollen, south-west of which place it enters England. There is evidence that where the ice-sheet abutted against Wales it was about 1350 feet in thickness. This is analogous to the thickness of the ice-sheet in Pennsylvania, where the author had previously shown that it was about 1000 feet in thickness at its extreme edge and 2000 feet thick at points some eight miles back from its edge. The transport of erratics coincides with the direction of striæ in Wales as elsewhere, and is at right angles to the terminal moraines.

The complicated phenomena of the glaciation of England, the subject of a voluminous literature and discordant views, had been of high interest to the author, and had led him to redouble his efforts toward its solution. He had found that it was possible to accurately map the glaciated areas, to separate the deposits made by land ice from those due to icebergs or to torrential rivers, and to trace out a series of terminal moraines, both at the edge of the ice-sheet and at the edge of its confluent lobes. Perhaps the finest exhibition of a terminal moraine in England is in the vicinity of Ellesmere, in Shropshire. A great mass of drift several miles in width and full of erratics from Scotland and from Wales, is here heaped into conical hills which enclose "kettle holes" and lakes, and have all the characters of the "kettle moraines" of Wisconsin, Like the latter, the Ellesmere moraine here divides two great lobes of ice, one coming from Scotland the other from Wales. This moraine may be traced continuously from Ellesmere eastward through Hadeley, Macclesfield, to and along the western flank of the Pennine chain, marking throughout the southern edge of the ice-sheet of Northern England. From Macclesfield the same moraine was traced northward past Stockport and Staley bridge to Burnley and thence to Skipton in Yorkshire. Northeast of Burnley it is banked against the Boulsworth hills up to a height of 1300 feet in the form of mounds and hummocks. South and east of this long moraine no signs of glaciation were discovered, while north and west of it there is every evidence of a continuous ice-sheet covering land and sea alike. The striæ and the transport of boulders agree in proving a southerly and south-easterly direction of ice-movement in Lancashire and Cheshire.

From Skipton northward the phenomena are more complicated. A tongue of ice surmounted the watershed near Skipton and protruded down the valley of the Aire as far as Bingley, where its terminal moraine is thrown across the valley like a great dam, reminding one of similar moraine dams in several Pennsylvania valleys. A continuous moraine was traced around this Aire glacier. Another great glacier, much larger than this, descended Wensleydale and reached the plain of York. The most complex glacial movements in England occurred in the mountain region about the Nine Standards, where local glaciers met and were overpowered by the greater ice-sheet coming down from Cumberland. The ice-sheet itself was here divided, one portion going southward, the other, in company with local glaciers and laden with the well-known boulders of the "Shap granite," being forced eastward across Stainmoor forest into Durham and Yorkshire, finally reaching the North sea at the mouth of the Tees. The terminal moraine runs eastward through Kirby Ravensworth toward Whitby, keeping north of the Cleveland hills, and all Eastern England and south of Whitby appears to be non-glaciated. On the other hand all England north of Stainmoor forest and the river Tees, except the very highest points, was smothered in a sea of solid ice.

There is abundant evidence to prove that the ice-lobe filling the Irish sea was thicker towards its axis than at its edges, and at the north than at its southern terminus, and that it was reinforced by smaller tributary ice-streams from both England and Ireland. It may be compared with the glacier of the Hudson River valley in New York, each having a maximum thickness of something more than 3000 feet. The erosive power of the ice-sheet was found to be extremely slight at its edge but more powerful farther north, where its action was continued for a longer period. Towards its edge its function was to fill up inequalities rather than to level them down. It was held that most glacial lakes are due to an irregular dumping of drift rather than to any scooping action. Observations in England and Switzerland coinciding with those in America to confirm this conclusion. Numerous facts on both sides of the Atlantic indicate that the upper portion of the ice-sheet may move in a different direction from its lower portion. It was also shown that a glacier in its advance had the power of raising stones from the bottom to the top of the ice, a fact due to the retardation by friction of its lower layers. The author had observed the gradual upward passage of sand and stones in the Grindenwald glacier, and applied the same explanation to the broken shells and flint raised from the bed of the Irish sea to the top of Moel Tryfan, to Macclesfield and to Dublin mountains.

The occurrence of stratified deposits in connection with undoubted moraines was shown to be a common phenomenon, and instances of stratified moraines in Switzerland, Italy, America and Wales were given. The stratification is due to waters derived from the melting ice, and is not proof of submergence.

It was held that, notwithstanding a general opinion to the contrary, there is no evidence in Great Britain of any marine submergence greater than about 450 feet. It was expected that an ice-sheet advancing across a sea should deposit shell fragments in its terminal moraine.

The broad principle was enunciated that wherever in Great Britain marine shells occur in glacial deposits at high levels, it can be proved both by striæ and the transport of erratics that the ice advanced on to the land from out of the sea. The shells on Three Rock mountain, near Dublin, and in North Wales and Macclesfield, all from the Irish sea, the shells in Cumberland transported from Solway Firth, those on the coast of Northumberland brought out of the North sea, those at Airdree, in Scotland, carried eastward from the bottom of the Clyde, and those in Caithness from Moray firth, were among examples adduced in proof of this principle. The improbability of a great submergence not leaving corresponding deposits in other parts of England was dwelt upon.

It was also held that there was insufficient evidence of more than one advance in the ice-sheet, although halts occurred in its retreat. The idea of successive elevations and submergence with advances and retreats of the ice was disputed, and the author held that much of the supposed interglacial drift was due to subglacial water from the melting ice.

The last portion of the paper discussed the distribution of boulders, gravels and clays south of the glacial area. Much the greater part of England was believed to have been uncovered by land ice. The drift deposits in this area were shown to be the result in part of marine currents bearing icebergs during a submergence of some 450 feet. The supposed glacial drift about Birmingham and the concentration of boulders at Wolverhampton were regarded as due to the former agent, while the deposits at Cromer and the distribution of Lincolnshire chalk across Southern England was due to the latter. The supposed esker at Hunstanton was held to be simply a sea-beach, and the London drift deposits to be of aqueous origin. Thus the rival theories of floating icebergs and of land glaciers were both true, the one for Middle and Southern England, the other for Scotland, Wales and the north of England; and the line of demarkation was fixed by great terminal moraines.

The paper closed with an acknowledgment of indebtedness to the many geologists of England and Ireland who had uniformly rendered most generous assistance during the above investigation.

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SOME PECULIARITIES OF THE LOCAL DRIFT OF THE ROCKY MOUNTAINS.[1]

BY DR. THEO. B. COMSTOCK.

ALL authorities upon the subject of the glacial deposits of the Rocky Mountain region agree in describing them as local or much restricted in extent. Some writers dismiss the matter with this remark, leaving it to be inferred that in other respects the character of the drift is quite similar to the well-known débris of the Eastern United States. Others have been more explicit and have shown how special conditions of topography have affected the accumulations in certain localities. In all cases where the details have been given the evidence is strong of excessive erosion, but almost invariably the transportative effects have been remarkably slight. As a natural result we meet with much variety in the gulches and gorges which can be traced to such an origin, while the diluvium of the subsequent melting period is made up of homogeneous materials in each instance, but wholly of local detritus. This gives to many of the unmodified morainal deposits a resemblance to alluvium which is quite striking. On the other hand, in some places (as notably near the head of Wind river, Wyoming) iceberg deposits are well simulated by the collections of boulders which have evidently rolled down the steep

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[1] Paper read before the A. A. A. S., Section E, Buffalo, 1886.